



Undergraduate Student Experiences with Citizen Science Highlight Potential to Broaden Scientific Engagement

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ABSTRACT

Opportunities for marginalized students (such as women, Black, Latinx, and Indigenous students, first-generation college students, LGBTQ+-identified individuals, and people/persons with disabilities) to engage in undergraduate research can help increase their persistence in STEM degrees and careers. The incorporation of citizen science projects into higher education provides unique opportunities for undergraduate students to get involved in scientific research, yet there is still much to be learned about how students, especially those with marginalized identities, interact with and perceive citizen science in higher education settings. Our goal was to understand student perspectives on citizen science, examine connections between participation in citizen science and student interest and sense of belonging in science, and explore how this varies based on demographic attributes. We did this using a case study with a mixed-methods design: a survey of students at a large predominantly white institution (PWI) (n = 143) and interviews with a subset of citizen science participants (n = 6). Results indicate that participation in citizen science occurred both within and outside of traditional classroom settings. Citizen science was valued most by students with an existing interest in science, and students who participated in citizen science projects reported a stronger sense of belonging in science. Our study uncovered challenges and misconceptions related to citizen science participation within higher education settings, highlighting the need for a commitment to broadening participation. Additional investigations of student perspectives regarding citizen science could allow for broader engagement of citizen science projects in higher education, ultimately helping to retain marginalized students in STEM.

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INTRODUCTION AND BACKGROUND

Women, Black, Latinx, and Indigenous students, first-generation college students (FGCSs), LGBTQ+-identified individuals, and people/persons with disabilities experience marginalization in many undergraduate science programs (Dika and D'Amico 2016; Hughes 2018; National Science Foundation 2019). While the reasons behind these disparities are complex and multi-faceted, research documents that science degree programs do not retain individuals from marginalized groups at the same rate as their peers (Chang et al. 2014; Dika and D'Amico 2016; Espinosa 2011; Hughes 2018). The ramifications of this persistent trend extend far beyond higher education. Most well-paying science jobs require post-secondary credentials at the bachelor's level or higher (Fayer, Lacey, and Watson 2017). In addition, diverse professionals are needed to approach scientific problems in inclusive, innovative ways. It is imperative that institutions of higher learning uncover and address factors that shape the retention of students from marginalized groups in science through college and beyond.

Interest in science appears to be a key component of student persistence in STEM in the short and long term (Maltese and Tai 2010). The construct of interest is commonly defined as an interaction between a person and an object (a thing, topic, or activity, such as STEM) in a particular environment (Hidi and Renninger 2006; Krapp 2002). Interest development requires both an emotional and cognitive attachment to an object, which are developed through positive interactions with an object in a given setting (Hidi and Renninger 2006; Krapp and Prenzel 2011). Over time, an individual's interests act as intrinsic motivators that inspire one to embark on experiences, build knowledge, and pursue certain career aspirations (Krapp and Prenzel 2011; Lent et al. 2008; Talley and Ortiz 2017). Research suggests that undergraduates majoring in scientific fields frequently possess long-standing interests in science that are well established by early adolescence (Maltese and Tai 2010). At the same time, interactions with the environment can play an important role in determining the trajectory of scientific interest over time. Young women, for example, commonly experience a decline in science interest as they enter their teenage years—a trend that is shaped by forces such as lack of female role models; peer, parental, and educator biases; and stereotype threat (Choney 2018). Talley and Martinez Ortiz (2017) found family encouragement to be an important motivator of ongoing interest development for Black and Latinx female undergraduates studying STEM, and other studies have noted the important role of underrepresented faculty mentors (Jimenez et al. 2019). Thus, although development

of a student's scientific interest is highly internal, it is still driven in part by external influences.

Postsecondary science environments such as classrooms and labs are inherently social settings. When students are accepted and valued in such environments, they feel empowered to further develop their scientific interests and gain a sense of belonging in their scientific spaces (Strayhorn 2019). Sense of belonging allows students to perceive themselves as legitimate members of a scientific group and promotes the development of a scientific social identity (Kim, Sinatra, and Seyranian 2018). Given that the customs and cultures of science settings remain heavily influenced by white, masculine, cis-heteronormative, affluent norms and values, marginalized students are more likely to report a lower sense of belonging in postsecondary science settings (Atherton et al. 2016; Banchevsky, Lewis, and Ito 2019; Johnson et al., 2012; Kim, Sinatra, and Seyranian 2018; Lee 2016; Rainey et al. 2018). As a result, such students are restricted from developing a social identity in their scientific field. Evidence suggests that students who feel less scientific belonging are less likely to persist in their discipline (Kim et al. 2018; Lewis et al. 2016; Puritty et al. 2017; Rainey et al. 2018).

Colleges and universities play an important role in creating scientific environments that challenge dominant group norms and broaden who is encouraged to pursue and who belongs in science (Ceglie 2011; Chang et al. 2014; Espinosa 2011; Graham et al. 2013). Indeed, marginalized students who report sustained, positive engagement in college science classes and co-curricular activities such as learning communities, clubs, and undergraduate research demonstrate greater persistence in science degree programs and careers (Ceglie 2011; Chang et al. 2014; Espinosa 2011; Getzel and Thoma 2008; Graham et al. 2013; Lillywhite and Wolbring 2019; Shapiro and Sax 2011). A growing number of initiatives exist to encourage and support the scientific engagement of college students with traditionally excluded identities and backgrounds (Hernandez et al. 2013; Jones et al. 2010; Schultz et al. 2011; Slovacek et al. 2012). The present study explores the potential of citizen science to promote the inclusion of students from marginalized groups in science.

Citizen science is a collaborative endeavor in which individuals from a variety of backgrounds (including those with little to no formal scientific training) contribute to the advancement of research by collecting and analyzing scientific data (Bonney et al. 2014). Citizen science projects originated with engagement of publics outside of formal educational settings but has rapidly expanded to engage a variety of sectors and to produce a broad array of learning outcomes (Bonney 2021; Phillips et al. 2018). Integration of citizen science at the postsecondary education level

remains less common than in pre-collegiate and informal education settings (Ballard, Dixon, and Harris 2017; Vitone et al. 2016). Oberhauser and LeBuhn (2012) argued that citizen science is beneficial to the undergraduate classroom as it employs active, inquiry-based learning, allows students to delve deeper into course material through authentic engagement with various components of the scientific process, and serves as a community service-learning opportunity for students. Existing literature on citizen science participant benefits in higher education focuses on specific learning outcomes and changes in scientific literacy (Mitchell et al. 2017; Oberhauser and LeBuhn 2012; Vitone et al. 2016). Less is known about how undergraduate students conceptualize citizen science and how citizen science participation influences non-cognitive outcomes such as science interest, sense of belonging, and persistence.

Research on the experiences and outcomes of individuals from marginalized groups who participate in citizen science is currently limited to informal education settings. Such studies document that people from racial and ethnic groups underrepresented in science are less likely to participate in citizen science projects (Pateman, Dyke, and West 2021), a trend due in part to a lack of alignment between citizen science initiatives and community interests (Pandya 2012). A need exists to examine how undergraduate students, particularly those underrepresented in their fields, interact with citizen science in and outside of the classroom. Such knowledge will improve and broaden citizen science engagement across various educational settings and could help to transform the way historically marginalized students engage with STEM.

Our research explores undergraduate student experiences with citizen science and examines if citizen science participation serves as a catalyst for scientific interest and a source of belonging for students historically marginalized in science. Specific objectives of this study include

1. characterizing undergraduate students' experiences with citizen science, including where that participation is occurring and who is participating (by academic major and demographic attributes);
2. identifying associations among students' participation in citizen science, academic major, demographic attributes, and interest and belonging in science; and
3. exploring how students perceive and interact with citizen science in higher education settings, investigating its potential to broaden scientific engagement.

STUDY CONTEXT

This research was conducted at North Carolina State University (NC State), a predominantly white institution (PWI) and public land-grant university with a Fall 2021

enrollment of 25,973 undergraduate students (Office of Institutional Research and Planning n.d.). NC State provides a unique opportunity to analyze the relationship between undergraduate students and citizen science because it has the first Citizen Science Campus program. The Citizen Science Campus program, organized by the Chancellor's Faculty Excellence Program in Leadership in Public Science, supports faculty and students in research, education, and service opportunities involving citizen science. Undergraduate students of all majors may encounter citizen science throughout many aspects of campus life including academic courses, resident hall programs, library events and loaning programs, undergraduate research experiences, work-study experiences, and a student organization, the Citizen Science Club. We collected data across the entire university rather than limiting collection to a specific classroom and/or citizen science project.

METHODS

We used a mixed-methods sequential explanatory design in which the quantitative component occurred first and informed the qualitative analysis (NCSU IRB #17996). In this way, the qualitative data allowed us to elaborate on the quantitative component to produce a more in-depth analysis (Ivankova, Creswell, and Stick 2006).

QUANTITATIVE METHODS: SURVEY

For the first step in our mixed methods design, we used an online survey to characterize citizen science participation among NC State students. Working with university administrators, we obtained a contact list of 2,000 randomly selected undergraduate students during Fall 2019. We sent an email link with a Qualtrics-based web survey to these students, yet only three out of these 2,000 students filled out the survey. Because of this low response rate, we contacted additional undergraduate students using two other strategies: convenience sampling that targeted email listservs and in-class announcements in upper-level ecology courses. Combined, these three methods resulted in 143 responses.

We designed survey questions to ascertain how students were introduced to citizen science, and whether their participation varied based on their demographic attributes. To understand where past citizen science participation was occurring, students were given the following definition of citizen science: "the collection and analysis of data relating to the natural world by members of the general public, typically as part of a collaborative project with professional scientists" (Oxford British and World English Dictionary). After being given a definition of citizen science, students

were asked if they had ever participated in citizen science as part of an undergraduate course and/or participated in a citizen science project that was not part of an undergraduate course with the option of selecting “Yes” or “No” (Supplemental File 1: Appendix 1.1). In addition, those who responded saying they had not participated in citizen science were asked about their interest in and likelihood of participating in citizen science in the future by responding to Likert-style questions with a five-point scale ranging from “Very interested” and “Very likely” to “Not at all interested” and “Very unlikely.”

We collected demographic information using questions created by Fernandez et al. (2016), including questions regarding parents’ highest level of education, underrepresented minority status, disability status, gender and sexual orientation, and academic major (STEM versus non-STEM) (Supplemental File 1: Appendix 1.1). In this research, marginalized students in STEM consist of underrepresented students of color, women, sexual and gender minorities (SGM), FGCSs, and people/persons with disabilities. Underrepresented students of color include those who are African American/Black, Hispanic or Latinx, Native American, Alaska Native, and/or Native Hawaiian/Pacific Islander. SGM students include those who identify as nonheterosexual and noncisgender (Mansh et al. 2015) and FGCSs include students with no parents/guardians who have attained a four-year degree. Components of a disability include (but are not limited to) mobility, sensory, learning, mental health, and long-term and short-term illness and/or injury (Fernandez et al. 2016). In this research, we categorized STEM majors as students who were pursuing a science, engineering, textiles, agriculture, and/or natural resources degree. We categorized non-STEM majors as students pursuing an education, business/management, design and/or humanities and social science degree.

We used quantitative methods to understand whether students’ sense of belonging and interest in science varied based on participation in citizen science, academic major, and/or demographic information. We adapted the survey questions from existing validated scales. We adapted the sense of belonging scale from Good, Rattan, and Dweck (2012) by substituting “scientific community” for “math community.” This included six Likert-style questions such as “I feel that I belong to the scientific community” with a five-point scale ranging from Agree to Disagree (Supplemental File 1: Appendix 1.1). We used the STEM semantics survey instrument created by Tyler-Wood, Knezek, and Christensen (2010) to measure students’ interest in science. Students responded to the prompt “To me, science is...” by responding to five different bipolar scales ranging from 1 to 5 (e.g., interesting to boring, appealing to unappealing).

We first examined descriptive statistics to characterize citizen science participation and demographic correlates (Objective 1). We used two-sample t-tests to compare student interest and sense of belonging in science for two groups: those who had and had not engaged in citizen science (Objective 2). We then used logistic regression to model associations of students’ academic major, demographic attributes, and science interest and belonging with the binary response variable, participation in citizen science (Objective 2; [Table 2](#)). At the end of the survey, students were asked if they were interested in a follow-up interview, to explore how students’ perceive and interact with citizen science in higher-education settings (Objective 3).

QUALITATIVE METHODS: INTERVIEWS

In the second step of our mixed methods design, we developed eight open-ended interview questions building on the quantitative survey and invited a subset of students who completed the initial survey to participate. We interviewed six students who answered survey questions in the first stage of data collection. All participants indicated they participated in citizen science and were in their second year of college or higher and were pursuing a STEM degree. All the participants were white, with one participant being multiracial (Black/African American and white). Nearly all the participants identified as a woman and/or a gender minority, with one participant identifying as a man. Four of the participants identified as a SGM, two of the participants were people/persons with disabilities, and no FGCSs were interviewed. All interviews were conducted in a private room at the university library. Interviews ranged from 15 to 45 minutes and were audio recorded.

We derived the interview questions from survey questions and focused on student perspectives on both science and citizen science. Students were asked about their interest in science (e.g., “Do you have a personal or professional interest in science?”), sense of belonging within scientific communities (e.g., “How would you describe your experiences within scientific communities? How would you describe your level of comfort within scientific communities? Have you encountered others like you in scientific communities?”), science attitudes (e.g., “How do you feel about science? What do you value or disvalue about science?”), and science identity (e.g., “Do you have a significant memory of your first encounter with science? Or any significant memories with science?”). Students were also asked about their experiences with citizen science (e.g., “Is there anything you would like to change about your experience with citizen science on campus?”), and how that influences their relationship with scientific communities (e.g., “In what ways has citizen science

influenced your perspective on scientific communities?”) (Supplemental File 2: Appendix 1.2).

Qualitative data were analyzed via the constant comparative method in which interview responses were coded, categorized, and connected to create key categories and concepts (Boeije 2002). After initial open coding, in which each line of textual data was coded and examined for common words, phrases, and expressions, we organized open codes into overarching axial codes or themes (Ryan and Bernard 2003). These larger themes helped us understand individual student experiences with citizen science, where these experiences occur within higher education settings, and how they may or may not influence students’ sense of belonging in scientific communities and/or interest in science.

POSITIONALITY STATEMENT

The lead author of this study conducted this research as an undergraduate student in an effort to better understand the perspectives of peers who participated in citizen science, a position that might have influenced the research process (Bourke, 2014). Their personal experiences as a FGCS and SGM in STEM, as well as their experiences with various student organizations focused on citizen science, public science, and visibility for historically marginalized groups in STEM, helped define the focus of the study. As a white, FCGS and a SGM, they understood their position as an undergraduate researcher as having a connection with participants they shared a marginalized identity with, as well as having privilege due to their race and ability status. However, it was the lead author’s efforts in various citizen science-centered organizations, along with their shared identity as an undergraduate student, that helped generate more candid responses.

The research questions in this study were driven by the lead author’s involvement with the Citizen Science Club at NC State. This undergraduate student organization is based around the saying that “Science is for Everyone” and stresses that science is an interdisciplinary endeavor. Students in this club are not only citizen scientists but champions of community action and inclusion in STEM.

RESULTS

QUANTITATIVE

Out of the 143 student respondents, 52 students had participated in citizen science as an undergraduate at NC State and 90 students had not. Of the 52 students who had participated, the largest group (40%) had participated only as part of a course, though 30% had participated outside of a classroom setting (**Figure 1**). Our survey sample had a higher representation of marginalized students when compared with the greater NC State undergraduate population. The sub-sample of students who participated in citizen science also had a higher representation of marginalized students than the sub-sample of students who did not participate in citizen science. Even though citizen science participants were more likely to be STEM majors, 31% were from disciplines outside of STEM (**Table 1**).

Students who participated in citizen science ($M = 3.54$, $SD = 1.1$) reported a significantly higher sense of belonging in science than those who had not participated ($M = 2.98$, $SD = 1.18$; $t(140) = -2.8$, $p = .006$; **Figure 2**). Interest in science did not differ between students with and without citizen science experience ($t(140) = -1.4$, $p = .174$; **Figure 2**; **Table 2**). When simultaneously examining interest, belonging, and demographic correlates, we found that citizen science participation was associated with students who had a

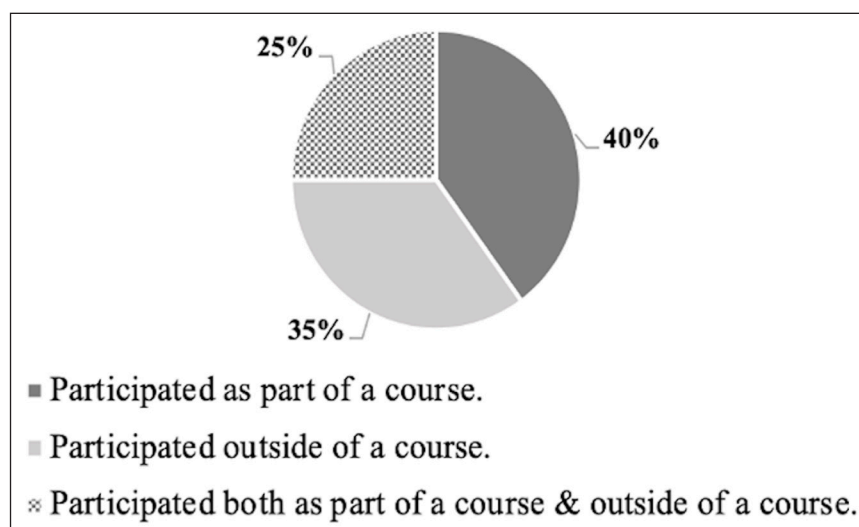


Figure 1 Nature of citizen science participation for undergraduate students at NC State University (n = 143).

CHARACTERISTIC	PARTICIPATED IN CITIZEN SCIENCE (N = 52)	HAS NOT PARTICIPATED IN CITIZEN SCIENCE (N = 90)	TOTAL NUMBER OF PARTICIPANTS	NC STATE FALL 2019 UNDERGRADUATE POPULATION (N = 25,973)
Gender identity				
Men	26.9%	35.2%	46	52.5%
Women	65.4%	59.3%	88	47.5%
Sexual and/or gender minority				
Yes	34.6%	22.0%	38	N/A
No	59.6%	73.6%	98	N/A
Underrepresented students of color				
Yes	15.4%	12.1%	19	12.5%
No	84.6%	87.9%	124	74.3%
First-generation college student				
Yes	23.1%	16.5%	27	N/A
No	76.9%	83.5%	116	N/A
Disability status				
Yes	17.3%	11.0%	19	3.6%
No	75%	81.3%	113	N/A
Academic major				
STEM	69.2%	42.2%	74	57.2%
Non STEM	30.8%	57.8%	68	29.5%

Table 1 Participation in citizen science based on students' demographic information and academic major.

Note: Data on North Carolina (NC) State fall 2019 undergraduate population pulled from the following sources:

Office of Institutional Research and Planning. n.d. "NC State University—Fall 2019 Enrollment Report" NC State University.

Disability Resource Office. n.d. "DRO Demographics" NC State University.

greater sense of belonging in science ($b = 0.61$, $p = 0.027$, $OR = 1.83$ (95% CI: 1.07, 3.16) and those who identified as a gender and/or sexual minority ($b = 1.08$, $p = 0.028$, $OR = 2.93$ (95% CI: 1.12, 7.66) (**Table 2**).

Citizen science participation rates were also higher among historically marginalized groups of students (e.g., women, students of color, FGCSs), but these differences were not statistically significant (**Table 2**).

QUALITATIVE

Four out of the six students interviewed participated in citizen science outside of a course, one within a course, and one within and outside of a course. Of the four students who participated outside of a course, three described experiences that took place as part of an extracurricular activity such as a student organization or residence hall community.

The qualitative findings showed that students conceptualize citizen science in various ways. Even though all students selected for interviews had reported experiences

in citizen science, throughout the interviews, it became apparent that students had varied understandings of citizen science. Respondents fell into two groups—those who struggled to conceptualize citizen science, and those who did not. The group of respondents who struggled to conceptualize citizen science consisted of two students who asked for definitions of citizen science and one who considered online surveys to be citizen science. The group of respondents who didn't struggle to conceptualize citizen science seemed to have high engagement: They all listed projects in which they'd participated, with one helping to carry out a project in public schools, and one helping with a project in an exhibit.

In the analysis of interviews, we identified three core themes related to undergraduate student perspectives on citizen science: Citizen science is beneficial to students with a strong personal interest in science; there's a feeling of a lack of belonging in science, and there are ways citizen science mitigates this; and there is a lack of citizen science opportunities in higher education (**Table 3**).

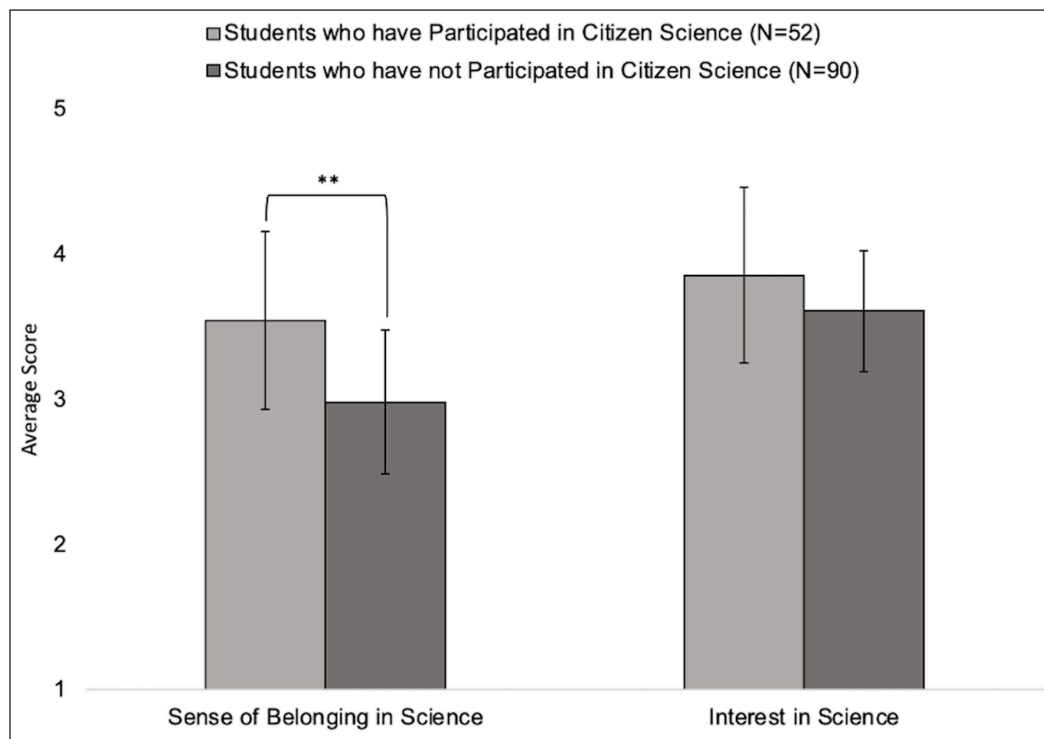


Figure 2 Students' mean sense of belonging and interest in science based on participation in citizen science compared using two-sample t-tests. * = $p < 0.05$; ** = $p < 0.01$.

PREDICTOR	MEAN	B	SE(B)	ODDS RATIO
Woman	0.66	0.37	0.45	1.45
Underrepresented student of color	0.12	0.15	0.64	1.16
Sexual and/or gender minority	0.28	1.08	0.49	2.93*
First generation college student	0.19	0.25	0.55	1.29
Disability status	0.14	0.64	0.62	1.90
STEM major	0.52	0.75	0.62	2.11
Science interest	3.70	-0.43	0.28	0.65
Science belonging	3.19	0.61	0.28	1.83*
Model summary				
n	121			
df	8			
X ²	17.28*			
Pseudo-R ²	0.11			

Table 2 Logistic regression model showing associations between citizen science participation, demographic attributes, and interest and belonging in science among undergraduates at the study institution.

* $p < 0.05$.

The first theme describes student respondents' early and continued interest in science, with one student saying, "...it has always been a passion of mine to discover different things," and describing how their personal interest

in science led to their participation in citizen science projects. This desire to pursue citizen science as part of one's personal interest can be seen in the following quote from an interview in which one student describes why they

CODE	DESCRIPTION	EXEMPLAR QUOTE(S)
Citizen science beneficial to students with a strong personal interest in science	Association of participation in citizen science with personal interest in science; describing interesting in science beginning at early age; positive feelings towards science.	<p>“...it has always been a passion of mine to discover different things.”</p> <p>“So there’s not always a- there’s a little bit of a personal element to that too, that that kind of, you know. I want to help, you know, I want to help researchers, and I want to help people give out life saving information to other human beings. But I actually really want to see this for myself because this is exhilarating to me.”</p>
Lack of belonging in science, how citizen science mitigates this.	Women and gender minority respondents indicating feelings of exclusion and uncomfortableness; feelings of being ignored in science communities as a result of gender identity. Descriptions of viewing citizen science as a challenge to stereotypes of who scientists are and where science is done; viewing the participatory aspect of citizen science as making science more accessible.	<p>“It’s like male dominated field is all about STEM. So, it’s like a female presenting individual going into that – it’s like, are they going to believe anything I say? Are they going to listen to me? Who knows?”</p> <p>“...this particular conference was predominantly white men and it made me feel very uncomfortable because it was like me and one other girl.”</p> <p>“It [citizen science] made me realize that the scientific community is more inclusive, like in the sense that they often allow the public to participate. And I mean, it kind of gives you the platform to go out, not do whatever you want, but like explore any avenue that you find interesting.”</p> <p>“So instead of thinking that like, oh, I can’t be a scientist because I’m not that old white guy, through citizen science, that understanding that your contribution, regardless of where you’re from, matters.”</p>
Lack of citizen science opportunities in higher education	Noting a lack of citizen science opportunities on campus, viewing the lack of opportunities as a limiting factor to their participation.	<p>“...awareness of ongoing research projects being done by professors, graduate students or undergraduate researchers like yourself, would be very important because sometimes it’s hard to find information on that.”</p> <p>“I mean, I kind of wish maybe there was a little bit more [citizen science], because I feel like we do a lot of closed off assignments or projects that are in the class, but they don’t exactly go any further than that assignment’s due date.”</p> <p>“I just wish there was more of it.”</p>

Table 3 Key codes and example quotes of interview analysis of college students who participated in citizen science.

participated in a citizen science project: “So there’s not always a- there’s a little bit of a personal element to that too, that that kind of, you know. I want to help, you know, I want to help researchers, and I want to help people give out life saving information to other human beings. But I actually really want to see this for myself because this is exhilarating to me.”

The second theme arose from descriptions given by various respondents regarding their feelings of exclusion in scientific communities. For example, one respondent said, “...this particular conference was predominantly white men and it made me feel very uncomfortable because it was like me and one other girl.” This theme also became apparent through the way students view citizen science as making science more accessible owing to its participatory nature and the way it challenges stereotypes around who a scientist is, as seen in one student’s response: “So instead of thinking that like, oh, I can’t be a scientist because I’m not that old white guy, through citizen science, that understanding that your contribution, regardless of where you’re from, matters.”

The final theme, the lack of citizen science opportunities in higher education, highlights that respondents feel as if there are not many opportunities for them to participate in citizen science at their university. As one said, “I mean, I kind

of wish maybe there was a little bit more [citizen science], because I feel like we do a lot of closed off assignments or projects that are in the class, but they don’t exactly go any further than that assignment’s due date.” Another student expressed a desire for more opportunities: “I just wish there was more of it.”

DISCUSSION

Our results suggest that, although citizen science remains on the periphery of undergraduate education, it has a unique potential to cultivate belonging and interest in science among students. Thus, citizen science could serve as a valuable approach to broadening the engagement of historically marginalized groups in STEM.

Our results revealed that students who participated in citizen science have a stronger sense of belonging in science. Marginalized students are more likely to report a lower sense of belonging in postsecondary science settings owing to pervasive white, masculine, cis-heteronormative, affluent norms and values present in science settings (Atherton et al. 2016; Banchevsky, Lewis, and Ito 2019; Johnson et al. 2012; Kim, Sinatra, and Seyranian 2018; Lee 2016; Rainey et al. 2018). Interestingly, student

respondents cited citizen science's ability to challenge these stereotypes, noting that is one of the things that makes participation in citizen science appealing. Students interviewed describe how citizen science made science more accessible to members of the public who may not traditionally engage in the research process. Although students see a potential for citizen science to make science accessible, they did not describe this process occurring for them specifically. Those interviewed described feeling excluded in scientific settings through personal experiences, and sense of belonging is highly contingent upon how students perceive themselves within scientific communities (Kim, Sinatra, and Seyranian 2018). Citizen science may open new pathways to belonging for groups that have been historically marginalized in STEM. Future research could explore ways to leverage these opportunities to enhance sense of belonging in science, helping to recruit new students into STEM and engage those who might feel excluded or unwelcome.

Our findings regarding interest in science were equivocal and inconclusive. Quantitative analysis yielded mixed findings regarding the relationship between interest in science and citizen science participation. This may partially stem from the fact that many students participating in citizen science are asked to do so as part of class, leading to more extrinsic motives for participation. Whereas extrinsic motivations may be important for initial recruitment, intrinsic motivations centered on personal interest and enjoyment are often needed for sustained participation in citizen science (Larson et al. 2020; Tiago et al. 2017). Qualitative data showed that students with a strong interest in science enjoy participating in citizen science because it is an activity that fuels their passion. Many students described how their interest in science began in childhood, which aligns with research suggesting science interest is formed and sustained throughout early adolescence (Maltese and Tai 2010). Research also indicates that external influences such as peers, stereotype threat, and family dynamics can positively or negatively impact interest in science for marginalized groups pursuing an undergraduate degree (Choney 2018; Talley and Ortiz 2017). Citizen science participation might not be enough to outweigh and overcome some of these other contextual and cultural barriers, but it could help foster a sense of community within science that might fuel future interest (Rotman et al. 2014). Although our sampling approach did not allow us to draw concrete conclusions about the ability of citizen science to enhance and sustain interest in science, it highlights the need for future research in this arena.

Our quantitative results showed that sexual and gender minorities were more likely to participate in citizen science compared with their heterosexual or cisgender peers. This

underscores the potential of citizen science as a tool for advancing social justice and inclusion in science (Makuch and Aczel 2020), though this potential is not always realized (Cooper et al., 2021). Because of limited existing research on the relationship between sexual and gender minorities and STEM retention (Hughes 2018; Linley, Renn and Woodford 2018.), and the limited data of this study, more research is needed to better understand why sexual and gender minorities in our sample were more likely to participate in citizen science compared with heterosexual or cisgender students.

Despite the multitude of potential benefits, our study also revealed challenges to integrating citizen science into higher education. After being provided with a definition of citizen science in the survey, many students who participated in interviews were not clear about what citizen science was or what the term means. The low survey response rate might have been an artifact of this confusion and uncertainty as well. Qualitative results show a lack of consistency as to what students consider to be citizen science, and several students struggled to conceptualize citizen science. Some students described participating in existing citizen science projects (such as iNaturalist), while others described participating in online surveys, exhibiting a citizen science project at an event, or creating a project to be used in K-12 classrooms. Public participation in citizen science, and other participatory science endeavors, can occur in a variety of different contexts (Shirk et al. 2012), so students' perceptions seem to reflect a broad conceptualization of citizen science. This variation might help to explain the broad appeal of activities perceived as citizen science and its varied effects on interest and belonging in science.

Students at NC State participated in citizen science both within and outside of academic courses, with the greatest number of students participating within a course (*Figure 1*). However, most students who self-selected to be interviewed only participated in citizen science outside of the classroom and expressed a strong personal interest in science. Previous studies on citizen science in higher education focus on citizen science in the classroom (Mitchell et al. 2017; Oberhauser and LeBuhn 2012; Vitone et al. 2016), and do not take into consideration students who participate outside of the classroom. The findings of this research show that although classroom-based citizen science projects reach the most students, some students are participating outside of a class as a result of their intrinsic motivation and interest in science-related activities. This shows that exposure to citizen projects need not be limited to the classroom; outside academic experiences and extracurricular activities are fertile grounds for citizen science engagement, too. Efforts to promote citizen science on college campuses should therefore consider both formal project options integrated

into curricula and informal project options that students can pursue in their leisure time. The incorporation of citizen science into various classrooms, as well as other aspects of student life, would benefit students with an interest in science. These initiatives could begin by focusing on increasing awareness and understanding of citizen science among undergraduate students as a whole, helping to clarify the varied conceptualizations of citizen science uncovered in student interviews and the low response rates to our survey. Such initiatives could continue to provide a space on campus, both within and outside of classrooms, where students can engage with citizen science projects and STEM in new and exciting ways.

LIMITATIONS

There are several limitations to this study. Although we initially used random selection for recruitment, a convenience sampling technique was later used to augment the low response rate. This resulted in a sample that was not representative of the greater undergraduate student population. In addition, in part because NC State is a PWI, there were low (<30) sample sizes for several marginalized groups in STEM, including underrepresented students of color, FGCSs, and people/persons with disabilities. These low sample sizes reflect actual representation in the larger student population but make it harder to draw accurate conclusions based on our analysis. Although some degree of bias is inevitable in exploratory research of this nature, our sample provided a unique glimpse into the perceptions and STEM experiences of historically marginalized groups. Although a larger number of interviews would contribute to more robust analysis, participant responses from individuals in these historically marginalized populations helped to contextualize our findings and highlight the potentially inclusive power of citizen science.

There are many challenges to studying marginalized groups in STEM. Although sense of belonging and interest in science contribute to the persistence of marginalized groups in STEM (Maltese and Tai 2010), other key aspects, such as relationships with faculty and family, first-year classes, and pre-collegiate experiences factor in, too (Chang et al. 2014; Jimenez et al. 2019). We did not account for these factors in our study, which might explain the relatively low predictive power of our models. Although the marginalized groups in this study consist of underrepresented students of color, women, SGMs, FGCSs, and people/persons with disabilities, it is important to note that this is not an exhaustive list of marginalized groups in STEM programs. Future research could explore how these groups experience science and how that experience might be impacted by citizen science participation.

In this study, we did not measure any change in interest and belonging before and after participating, making it hard to distinguish between correlation and causation. There is value in assessing causality by employing a pre-post study design. For example, future studies could measure changes in factors such as interest and sense of belonging before and after participation in citizen science. This longitudinal approach would help researchers to better understand how students' attitudes toward science and beliefs about their own science efficacy change as a result of participation.

BROADENING FUTURE SCIENCE ENGAGEMENT WITH CITIZEN SCIENCE

Acknowledging the challenge of recruiting and retaining a diverse array of students and researchers in science, many universities have developed initiatives to make STEM disciplines more inclusive (Allen-Ramdiel and Campbell 2014). Unfortunately, many of those diversity initiatives fail to foster true inclusion (Purritty et al. 2017). Our findings suggest that citizen science has the potential to broaden science engagement on a college campus and to make STEM more accessible. Results highlight the need to create more chances for undergraduate students to experience citizen science, as well as the importance of evaluating outcomes of those experiences. This could be done by providing opportunities for students to participate in citizen science both within and outside of the classroom, and to increase awareness of citizen science among undergraduate students.

Future efforts to expand citizen science on college campuses should also explore student participation in different types of projects. Pandya (2012) argues for a more participatory approach to citizen science projects in which collaboration among people from diverse backgrounds occurs throughout the entirety of a project, from the creation of the project to the dissemination of results. This might create a more inclusive environment for marginalized groups in STEM (Purritty et al. 2017). Oberhauser and LeBuhn (2012) describe citizen science's inquiry-based approach as an opportunity to engage more deeply with course material by allowing students to participate in asking scientific questions and performing research. For example, integration of citizen science in undergraduate classrooms that encourages students to engage in the authentic scientific process (e.g., analyze data, assess its quality, publish articles, and participate in peer review) can lead to increased level of engagement, positive attitudes, and elevated science learning and efficacy (Mitchell et al. 2017; Vitone et al. 2016). Future research that investigates the ways in which citizen science can impact interest and

belonging in science, in addition to more conventional learning outcomes, could help to illuminate new strategies to broaden the engagement of all students—and especially historically marginalized students—in STEM programs.

DATA ACCESSIBILITY STATEMENT

Data not available due to ethical restrictions. Because of the nature of this research, participants of this study did not consent to sharing their data publicly.

SUPPLEMENTARY FILES

The supplementary files for this article can be found as follows:

- **Supplemental File 1.** Appendix 1.1 Student survey. DOI: <https://doi.org/10.5334/cstp.419.s1>
- **Supplemental File 2.** Appendix 1.2 List of structured interview questions. DOI: <https://doi.org/10.5334/cstp.419.s2>

ETHICS AND CONSENT

Approval for this study was obtained by the North Carolina State University IRB Office, approval number #17996.

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The authors have no competing interests to declare.

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